

Game, Set, Match:

A Mathematical Perspective Of The Creation Of A Tennis Board Game

An Honors Thesis (HONRS 499)

By

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Dr. Rebecca Pierce

A handwritten signature in cursive script that reads "Dr. Rebecca Pierce". The signature is written in black ink and is positioned above a horizontal dashed line.

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ABSTRACT

“Game, Set, Match” is my created version of a tennis game wherein 2 opposing players simulate a tennis match. My game is based on the baseball version of the Strat-O-Matic game. These games are predicated on the mathematical principles of probability and statistics to provide an accurate, realistic, and entertaining simulation of a tennis match. The first section of my project explains why I chose to develop my game. I begin by briefly explaining my love for tennis and mathematics, the foundation and motivation for designing “Game, Set, Match”. I wanted to illustrate that mathematical principles are useful in developing games. I list my interest in tennis as another reason to develop this game, along with the lack of tennis games not associated with computer games or video games. I explain the importance of designing a game for players to compile player statistics, and finish my first section by explaining the reasoning of giving my game a unique touch with the “wild card” feature.

My second section focuses on the game and player design. Basically, I go through a step-by-step process of how I designed my player cards and the mathematics involved. I include how the scoring rules of my game are similar or different from the professional scoring rules of tennis. I also include instructions, game symbols, and the equipment needed to play my game. The third section provides an example of a set simulation, along with player comments and feedback. My last section provides a summary of what I learned during the whole process, and what I could do to improve the game or develop it further.

Section I: Background

“Game, set, match!!” This phrase has often been uttered as the last point has been scored after a grueling duel between two tennis players, and no, it does not stand for wild animals, a volleyball shot, or an object that is struck to ignite a fire. For those not familiar with the game of tennis, an event pitting singles or doubles players against each other is called a match. Matches are subdivided into sets, sets are subdivided into games, and games are subdivided into points. The common observer may misunderstand even the most basic terms associated with the game of tennis.

“Mathematics.” For a majority of people when they hear this term, they cringe and scrunch their face into somewhat comical positions. I call this “distasteful disposition face.” To many, this term conjures up images of a mangled mass of numbers that need to undergo numerous mathematical operations which may seem as confusing as trying to perform a real operation without having the knowledge and expertise of a licensed doctor. For others who remember high school and college mathematics courses, they may shudder at remembering “symbol mathematics”, where students are introduced to a vast array of symbols, which include using letters as variables, along with using Greek symbols (π , α , σ , μ , etc.) to also represent certain characteristics of a collection of numbers, such as the mean and variance.

So, why would I mention the game of tennis and the term mathematics in the same sentence? Simply, they both are vital interests in my life. My love for tennis originated the summer before my freshman year at Ball State University. I enjoy watching professional tennis on television, but I immensely enjoy playing tennis. What started out as a very infrequent, irregular leisure pursuit has turned into a frequent, casual activity for me. Every summer since the aforementioned original summer, I have asked, pleaded, and literally dragged people to the

tennis courts to play against me, or even just shag balls for me while I practice my serve. My desire has even reached the point to where, during the winter, I have a yearning to go out to a tennis court, shovel off the snow, and practice my serve. Clearly, this proves how quickly the game of tennis has engulfed me in its excitement.

On the other hand, mathematics has been a nearly life-long love of mine. Mathematics has been my favorite subject since first grade. I can even precisely remember when my love of mathematics originated. My first grade classmates and I were learning about currency and its value, and we had to determine the least number of coins it took to come up with a particular value. At that point, when I learned the least amount of coins to come up with 57 cents is five (excluding the 50 cent coin), a spark was ignited in my brain, and my fondness for mathematics has been continually nurtured to this day.

So, naturally, for my senior project I wanted to delve into something that involved both tennis and mathematics. I then remembered a game I had played avidly for three or four years, beginning when I was 10 years old. This game was Strat-O-Matic baseball. I remember playing this game during the summer three or four nights a week, often into the wee hours of the morning, in my friend's basement. Strat-O-Matic is a company that produces board/card games for baseball, basketball, football, and hockey, which simulate a game of each respective sport. Strat-O-Matic just celebrated its 40th anniversary in February 2002, and over the years, Strat-O-Matic games have produced somewhat of a cult following. So, I decided to create a tennis version of these Strat-O-Matic games as my senior project.

By having people play my version of the Strat-O-Matic game, I wanted to illustrate that mathematical principles are useful in developing board/card/dice games. Many people who visit Las Vegas and Atlantic City already realize this phenomenon. People realize that when playing

poker, a royal flush will pay more than a full house, because the probability of being dealt a royal flush is lower. Consider the most recent men's college basketball season. Ball State University's odds of winning the NCAA national championship may be 1000 to 1, whereas Duke University's odds of winning the NCAA national championship may be 3 to 1. What does this mean? This means Duke University's men's basketball team is predicted to have a much greater chance of winning the tournament than Ball State University's men's basketball team. The odds-makers must consider a myriad of factors when determining these odds, such as quality of players, quality of coaching staff, strength of schedule, just to name a few factors. Assuming these numbers are the case, let's assume that Ball State University's men's basketball team won the NCAA championship. For anybody who wagered for Ball State, for every dollar this person wagered, this person would be entitled to \$1000, whereas if Duke won, for every dollar wagered, the person would be entitled to \$3. Again, the less likely the probability of an event happening, the greater the payout will be.

Many people are intrigued by probabilistic principles when they are directly and financially affected by the outcome of the event, but these principles are even used in games that are played when there is no money involved. Yahtzee is a perfect example. Rolling five of a kind is the best roll and constitutes the most points because it is the least probable roll. Even in board/card/dice games played just for fun, mathematics plays an integral role in determining the player's position by points, money won, etc. Even one of the most basic mathematical concepts, addition, is used to rank players and establish a standard to evaluate players.

People who understand and appreciate the principle that the value of an event increases as the chance of the event happening decreases are more likely to understand and appreciate how this principle applies to the Strat-O-Matic game, and to my tennis game, which I have entitled

“Game, Set, Match”. To explain this principle, I will use the baseball version as my example. As in my game, each player’s statistics and tendencies are examined, and then this information is distributed onto his/her player card. The player cards consist of 6 columns and 11 rows, with a total of 66 cells. So I will use two current Chicago Cubs players, Sammy Sosa and Augie Ojeda, as my examples.

Sammy Sosa is one of the most prolific home run hitters in the past 25 years. However, as is the case with most home run hitters, Sammy Sosa takes long, dramatic swings, which means he also is annually among the league leaders in strikeouts. In contrast, Augie Ojeda is a utility infielder with the Chicago Cubs, and at a height of 5’8” and a weight of 165 is one of the smallest Major League players. Augie Ojeda rarely hits home runs. Instead, he is a good contact hitter, which means he has a short, compact swing meant to make sure he makes contact with the ball. Therefore, he rarely strikes out. So how is this information disseminated onto the player cards? Let’s assume Sammy Sosa’s batting average (hits / at bats) is .300, and he strikes out four times every 10 at bats producing an out (.400 strikeout percentage). Therefore, on Sammy Sosa’s card, the probability of Sammy Sosa getting a hit will be distributed in the cells in such a way that the probability will be 30%. However, since Sammy Sosa is a prolific hitter, 50% of his hits may be home runs. So, if it is determined 20 cells are allotted for hits, he will have 10 cells ($20 * 50\%$) allotted for home runs. For all the “outs” Sammy Sosa produces, 20% of these will be strikeouts. So if 32 cells are accorded for outs, 13 cells ($32 * 40\%$) will be accorded for strikeouts.

For Augie Ojeda, we will assume his batting average is .225, and he strikes out one time every 20 at bats producing an out (.050 strikeout percentage). Therefore, on Augie Ojeda’s card, the probability of him getting a hit will be distributed in the cells in such a way that the

probability will be 22.5%. However, Augie Ojeda rarely hits home runs, so only 8% of his hits are home runs. If 15 cells are allotted for hits, he will have one cell ($15 * 8\%$) allotted for home runs. For all the "outs" Augie Ojeda produces, 5% of these will be strikeouts. If 47 cells are accorded for outs, two cells ($47 * 5\%$) will be allotted for strikeouts. These examples clearly show how probability is used to determine how to distribute statistics onto the player cards. Assuming they finished with nearly the same amount of at bats, if somebody were to wager that Augie Ojeda would hit as many home runs as Sammy Sosa in a season, that person would pocket a significant amount of money. The reason for the large amount is the probability of this happening is minutely small; the person accepting the bet would jump at the chance, thinking to himself or herself, "Man, this person is crazy to believe Augie Ojeda will hit as many home runs as Sammy Sosa."

Another reason I decided to create a tennis version of the Strat-O-Matic game was the non-existence of tennis games outside of the video game market. The beauty of my tennis game is that the game is based on accurate statistical data, and yet the outcome of each event during the game is not based on the controller's (the player *of* the game, not the player *in* the game) skill of using a joystick; the outcome is predominantly based on chance, although a minimal amount of the outcome may be based on the controller's strategic skills. In my game, in fact, the outcome is based entirely on chance. Video games do not entice me very much because every head-to-head game pitting one player against another will be determined by who has more expertise and who has better control over the game system on which the game is being played. It seems contradictory, and a little comical, that when I play my 18-year-old cousin in a certain tennis game, I can be Pete Sampras, and he will be Joe Sixpack, and he will still beat me in straight sets (which means he wins all the sets), and pretty easily at that. In the video game

world, he is Pete Sampras, and I am Joe Sixpack. However, it is somewhat amusing that I can make Pete Sampras look like a floundering fish out of water.

Another reason why my game should be appealing to a player is the easy accessibility and minimal equipment it takes to play the game. All you need are dice, player cards, and scorecards. My game can be played in a friend's basement, out in the middle of wilderness, on an airplane, even in Dr. Foley's MATHS 453 class. No electricity is needed for my game. I realize for people under the age of 20 that the concept of simulating a sports game without playing a video game or a computer game seems unfathomable, so my game is mainly geared towards people over the age of 20 who appreciate the splendor of playing board/dice/card games.

For people who are not very adept at playing video games and who find the mathematical aspects of tennis intriguing, my game is very appealing because it is designed for the players to keep statistics. After each roll of the dice, it is easy to record the tennis shot. This is virtually impossible with a video game, since the action occurs very rapidly. In fact, the ability to keep detailed statistics is one of the most appealing aspects of my game. If a player were to simulate a tennis player's season, record statistics, compare it with the actual results of that tennis player's season, the figures should be within the same ballpark of each other. However, just one season is not nearly enough to make an accurate assessment of whether or not the player cards are properly designed.

One statistical concept I have learned is that a broader range of actual data will decrease the accuracy of the estimated data. For example, if I were to compare Pete Sampras' actual 2001 results to his simulated results based on 1996 data, I would find a moderate deviation, since his style and level of play has remained relatively constant over that time period. Furthermore, if I were to compare his 2006 results to his simulated results based on 1996 data, I would find a very

— significant deviation. His style and level of play will have changed dramatically, mainly due to his age and the increasing quality of opposing players. In short, his level of play will decrease exponentially, which means his level of play decreased slightly from 1996 to 2001, but decreased significantly from 2001 to 2006, although the time frame is the same.

Another statistical concept I learned is that the more data that is compiled and compared over a range of time, the less deviation there will be over that range. For example, if I were to compare Pete Sampras' actual results every year from 1996 to 2006 to his simulated results based on 2001 data, I would most likely find that three or four years compared to the simulated results are pretty accurate, but six or seven years compared to the simulated results would be significantly different. However, if I were to base his player card on his average results from every year between 1996 to 2006, and then compare his actual results from every year between — 1996 to 2006 to his simulated results based on the 10-year average data, I would find less deviation overall.

These two statistical concepts explained above certainly illustrate the importance of data in a relevant range and the law of large numbers; any statistical game such as mine would be more accurate if these concepts are incorporated. The purpose of my game is to simulate a real tennis match as accurately as possible. However, as with any game, there are confinements and restrictions that prevent the simulation from being completely realistic. The most significant restriction of my game is the lack of any tangible statistics for a player's shot selection, thereby reducing the accuracy of my assumptions. Consequently, based on my limited knowledge of a player's tendencies, I created my own statistics for a player's shot selection. I tried researching this aspect of the game, but such detailed statistics are not recorded (or at least not made — available to the general public). On the other hand, this restriction provided me the most leeway,

— since my fabricated statistics are assumed to be actual results. If there were actual statistics for a player's shot selection, I would use these to proceed with my player design.

Another restriction to my game is in regards to a player's "vital" statistics (game record, set record, match record, records on each court, etc.). Strat-O-Matic annually creates every version of their game; therefore, player cards for a certain year are based on that year's actual results. In my game, I was able to obtain "vital" statistics for each player based only on his/her actual 2001 results. I compiled these statistics from the website www.sportslines.com/u/tennis/players/. However, I ran into some difficulties. I went to this website in late January to obtain my statistics, and found the detailed 2001 statistics that I needed for most players. However, the 2002 tennis season starts in mid-January, so for some players the results of the tournaments in which they played were already posted on the website, which erased their 2001 results. For my game I decided to include 16 players, eight males and eight females. For four players, the 2001 results were already erased, so I had to concoct my own statistics. I did this by comparing the player to the players for whom I had statistics, and appropriately ranking the player.

— Strat-O-Matic Game Company prides itself on providing minutely detailed and extremely accurate data, making the game as realistic as possible. I strive to provide this in my game as well. However, I wanted to provide my own unique "spin" on the game. My creation of the "wild card" makes this possible. The "wild card" provides a glimpse into the extreme, humorous aspects of tennis. The main purpose of the "wild card" in my game is simply as a means of entertainment. Basically, the "wild card" lists some comical situations that would rarely happen on the professional tour, but situations that may have occurred at some point to everyday players in a casual format. By combining the more unusual, bizarre aspects of tennis with the more

professional, structured aspects of tennis, I have made the game more appealing to my audience. My game is more marketable with some “spice” added to it, while at the same time not dramatically altering the outcome of the game. The accurate statistical information can be seen as the “meat and potatoes” of my game, whereas the “wild card” can be seen as the Tabasco sauce or steak sauce that gives my game a little bit more flavor.

Section II: Player Design

My first objective in setting up my player cards was to determine all the possible shots a player would most likely use during a tennis match. First, I categorized these by strokes. I determined four strokes: forehand, backhand, half volley, and overhead. Next, I needed to determine the different types of shots that are executed for each stroke. Since some shots are exclusive only to one type of stroke or the shot is very difficult to execute using a certain stroke, some strokes have more shots utilized than other strokes. After determining all the strokes and all the shots, I had to determine the type of spin created by each shot. There are two main spins: topspin and underspin. After determining this information, I categorized the information as follows:

Forehand & Backhand

Volley Topspin
Volley Underspin
Liner Topspin
Liner Underspin
Kill
Lob

Half Volley

Volley Topspin
Volley Underspin
Liner Topspin
Liner Underspin
Dink

Overhead

Volley Topspin
Smash

Each shot is categorized by stroke, with each stroke having a different number of shots. Most shots are also categorized by spin. However, notice some shots are not categorized by spin because these shots can be hit with either type of spin. For the purposes of my game and the frequency with which these shots are executed, I have deemed that subcategorizing these shots is insignificant.

After the categories were set, I needed to determine the percentage of shots executed by stroke and the percentage of shots executed within each stroke. Tennis is played at a feverish pace, so it is virtually impossible to record actual statistics by this criteria. Hence, my knowledge of tennis players and my creative abilities come into play. Based on my knowledge

of a player's tendencies, I simply created my own statistics. Here are my estimated statistics for Lindsay Davenport:

Forehand & Backhand (.803)		Half Volley (.123)		Overhead (.055)	
Volley Topspin	(.358)	Volley Topspin	(.317)	Volley Topspin	(.161)
Volley Underspin	(.232)	Volley Underspin	(.206)	Smash	(.839)
Liner Topspin	(.129)	Liner Topspin	(.295)		
Liner Underspin	(.091)	Liner Underspin	(.126)		
Kill	(.147)	Dink	(.056)		
Lob	(.043)				

You will notice that my stroke statistics add up to .981. They should add up to one, right? However, in my game, I have instituted a "wild card". This is where the remaining .019 is located. Within each stroke column, note that the statistics do add up to one. This covers the volley portion of my player card.

Another important aspect of the game is the serve. Again, I simply created my own serve statistics based on my knowledge of the players:

First Serve:			Second Serve:		
Ace	(.289)		Ace	(.147)	
Return	(.493)		Return	(.748)	
Fault	(.218)		Fault	(.105)	

Note the percentage of serving an ace and fault is higher for the first serve, since the server's focus is more on power and less on accuracy.

Player Card

For the game, you will need three six-sided dice and one 20-sided die. You will use the 20-sided die for serves and for the "wild card" option. For the volleys, you will roll the three six-sided dice. However, one of these dice must be distinguishable from the other two, since the distinguishable die will be rolled to determine the column (1-6) and the other two dice will be rolled to distinguish the row (2-12). Hence, there are 66 cells (6*11) into which all the volley

shots and the “wild cards” will be distributed. Now, probability comes into play. I have attached a Microsoft Excel worksheet (Figure 1) detailing how probability is used to distribute my shots. I have subcategorized each cell into two components: one component represents the shot executed when the opposing player approaches the net; the other component represents the shot executed when the opposing player does not approach the net. After determining that my denominator was 432, I multiplied 432 by each stroke statistic to come up with my “numerator” number to distribute my strokes. Once I obtained this number, I then multiplied this number by each shot statistic within that stroke to determine the “numerator” number to distribute my shots. For example, to get the Volley Topspin “numerator” number for Volley Topspin under the Forehand and Backhand category, I multiplied 347 by .357 to obtain 124. Shown below are all the values for Lindsay Davenport:

Forehand & Backhand	347	Half Volley	53	Overhead	24
Volley Topspin	124	Volley Topspin	17	Volley Topspin	4
Volley Underspin	81	Volley Underspin	11	Smash	20
Liner Topspin	45	Liner Topspin	16		
Liner Underspin	31	Liner Underspin	6		
Kill	51	Dink	3		
Lob	15				

Note that my stroke points only add up to 424. The remaining eight points are distributed in my “wild card” slots. Also notice that all the shot points within each stroke add up to the stroke points.

Now that I have these “numerator” numbers, what do they mean? If you look at Figure 1, you will notice that I have fractions within each cell. To distribute my shots, I have to make sure I allocate my shots so the sum of the numerator values equals the calculated values. For example, if you look at cell (3,11) on Davenport’s hard court player card, she executes a

Figure 1: Distribution of Probabilities

	1	2	3	4	5	6	Total
2	1/432 1/432	1/432 1/432	1/432 1/432	1/432 1/432	1/432 1/432	1/432 1/432	12/432
3	2/432 2/432	2/432 2/432	2/432 2/432	2/432 2/432	2/432 2/432	2/432 2/432	24/432
4	3/432 3/432	3/432 3/432	3/432 3/432	3/432 3/432	3/432 3/432	3/432 3/432	36/432
5	4/432 4/432	4/432 4/432	4/432 4/432	4/432 4/432	4/432 4/432	4/432 4/432	48/432
6	5/532 5/532	5/532 5/532	5/532 5/532	5/532 5/532	5/532 5/532	5/532 5/532	60/432
7	6/432 6/432	6/432 6/432	6/432 6/432	6/432 6/432	6/432 6/432	6/432 6/432	72/432
8	5/532 5/532	5/532 5/532	5/532 5/532	5/532 5/532	5/532 5/532	5/532 5/532	60/432
9	4/432 4/432	4/432 4/432	4/432 4/432	4/432 4/432	4/432 4/432	4/432 4/432	48/432
10	3/432 3/432	3/432 3/432	3/432 3/432	3/432 3/432	3/432 3/432	3/432 3/432	36/432
11	2/432 2/432	2/432 2/432	2/432 2/432	2/432 2/432	2/432 2/432	2/432 2/432	24/432
12	1/432 1/432	1/432 1/432	1/432 1/432	1/432 1/432	1/432 1/432	1/432 1/432	12/432

$$\begin{array}{ccccccc}
 & & & P(\text{Row}) & & P(\text{Column}) & P(\text{In cell}) \\
 1/432 & = & 1/36 & * & 1/6 & * & 1/2
 \end{array}$$

backhand volley with topspin. Since I determined the probability in row 11 for each shot is $2/432$ with both slots filled with this shot, the total probability is $4/432$. So, four points have been allocated for a forehand or backhand volley with topspin. Therefore, I have to fill a remaining $120/432$ ($124/432 - 4/432$) cells with a forehand or backhand volley with topspin. After doing this for all shots, I successfully filled all the player cards with their distribution of shots.

Next I determined which percentage of shots were winners, which were losers, and which were volleys. Initially, I was going to use the player's winning game percentage on a particular court, and then use this percentage as the percentage of winning shots to total shots. For example, Davenport's game record on hard courts was 550-369, which corresponds with a .598 winning game percentage on hard courts. I then would multiply this percentage by 424, not 432, since $8/432$ of the card slots were occupied by the "wild card". Therefore, $254/432$ ($.598 * 424$) of the player card would be occupied by winning shots. The remaining .402 of the card would be occupied by losing shots and volley shots. However, utilizing my knowledge of tennis, I realized that players, on average, volley back and forth a few times before a winning or losing shot is executed. Therefore, the volley percentage was going to be significantly higher than the 15% or 20% I originally presumed. Using a mathematical basis, I decided the volley percentage would be one minus the winning game percentage on that court. Thus, Davenport's volley percentage on hard courts was .402 ($1 - .598$), on grass courts .348 ($1 - .652$), on clay courts .452 ($1 - .548$), and on carpet courts .279 ($1 - .721$). Next I multiplied each volley percentage by 424 to determine my "numerator" numbers for volleys on each court: 170, 148, 192, and 118, respectively.

I determined the winning percentage next. Since I subtracted the player's game winning percentage from one to obtain the volley percentage, the remainder is the percentage of shots that

were winners and losers. For example, since .402 (1-.598) was used as the volley percentage, .598 remained as the percentage for winning and losing shots. To obtain the winning shot percentage, I multiplied the player's game winning percentage on each court by the player's overall set winning percentage. For Davenport's winning shot percentage on hard courts, I multiplied $.598 * .809$ (her overall set winning percentage) to obtain .484. I then multiplied this percentage by 424 to obtain the "numerator" number for winning shots: 205, 224, 188, and 247 for each court, respectively.

After determining the winning shot percentage, I could determine the losing shot percentage. This was obtained by multiplying the player's game winning percentage by one minus the player's overall set winning percentage. For Davenport's losing shot percentage on hard courts, I multiplied $.598 * .191$ (one minus her overall set winning percentage) to obtain .114. I then multiplied this percentage by 424 to obtain the losing shot "numerator" number. For Davenport these values turned out to be 49, 52, 44, and 59 for each court, respectively. Shown below are all the "numerator" numbers for Lindsay Davenport:

Hard		Grass		Clay		Carpet	
Volley	170	Volley	148	Volley	192	Volley	118
Winner	205	Winner	224	Winner	188	Winner	247
Loser	49	Loser	52	Loser	44	Loser	59

After determining these values, I was ready to distribute the volley shots, winning shots, and losing shots on my player cards. Some shots could already be categorized as winners by definition, so I labeled these shots first. For example, a "kill" and "smash" are winning shots, so I labeled these first. Some shots had a significantly large or small probability of being certain shots, so I labeled these shots next. For example, a "lob" shot is used mainly as a defensive shot, so this shot will rarely be a winner. Likewise, a "liner" shot is a well-placed shot that hits one of

the boundary lines, and any ball that hits at least part of the line is regarded as being in play. So this shot by definition is not a loser, and is usually, but not always, a winner. After these shots, I then labeled the remaining shots with regard to each particular court. For example, the ball generally moves the quickest and bounces the most on hard courts. So a player hitting the ball with topspin (a spin that produces a high bounce and travels very quickly) has a better chance of hitting the ball past the opponent or in a place where it is very difficult for the opposing player to reach the ball. So on hard courts, the player would have more topspin winners than underspin winners. The opposite is true for grass courts. A shot hit with underspin would be more beneficial, since underspin "deadens" the ball and produces a low bounce. Also, a ball does not bounce very much on grass, so the opposing player does not have time to run cross-court and return the ball in time. Therefore, more underspin winners will occur on grass courts. Clay and carpet courts fall in between hard courts and grass courts, so a fairly equal combination of topspin and underspin winners were appropriate for these courts. Incorporating all of these factors, the shots were randomly distributed on the player cards. However, I found the percentages of each shot on each particular court did not vary much. Consequently each player's four individual player cards are somewhat similar. This mirrors the fact that each player has his/her own style, so he/she will only make minor adjustments for each particular court.

After determining the distribution of volley shots, winning shots, and losing shots, I had to determine the percentage of volley shots where the player approached the net. Notice that I only need to determine the percentage of volley shots since on a winning or losing shot the ball is not returnable and there is no need to approach the net; the point is over. My mathematical formula for determining the approach shot percentage is: player's overall winning game percentage multiplied by player's overall winning set percentage multiplied by player's overall

winning game percentage. For Davenport, the formula for the approach shot percentage on hard courts is $.614$ (overall winning game percentage) $\times .809$ (overall winning set percentage) $\times .873$ (overall winning match percentage), which equals $.434$. I then multiplied this percentage by the player's volley shot "numerator" number on each court to determine the approach shot "numerator" number for each court. For Davenport, I multiplied $.434 \times 170$ (volley shot "numerator" number for hard court) to arrive at 74, her approach shot "numerator" number for hard court. These values turned out to be 74, 64, 83, and 51 for each court, respectively.

After determining the approach shot "numerator" number for each court, I distributed these onto the player cards, keeping in mind which shots were or were not practical approach shots. For example, if the player hits a "dink" shot, by definition the opposing player will approach the net, meaning that the player making the shot most likely will not approach the net.

Similarly, if the player hits a "lob" shot, this means the opposing player is near the back line, which is far away from the net, so this is a good opportunity for the player to approach the net. Figure 2 displays Lindsay Davenport's hard court player card.

Figure 2: Lindsay Davenport's Hard Court Player Card

Lindsay Davenport
HARD

First Serve:

1-6 ace

7-16 return

17-20 fault

Second Serve:

1-3 ace

4-18 return

19-20 fault

	1	2	3	4	5	6
	wild card	BH-volley TS	HV-liner TS (+)	BH-volley US (+)	FH-lob (+)	wild card
2	wild card	BH-volley TS	OH-smash	BH-liner TS	HV-liner US	wild card
	BH-volley TS	HV-liner TS (+)	FH-volley US	<u>BH-volley TS (+)</u>	FH-volley TS	BH-liner TS
3	BH-volley TS	OH-smash	FH-volley US	<u>HV-volley US</u>	FH-volley TS	BH-liner TS
	FH-lob (+)	<u>FH-volley US (+)</u>	FH-kill	BH-volley TS	<u>FH-liner US (+)</u>	<u>FH-volley US</u>
4	HV-dink	BH-liner TS	FH-kill	BH-volley TS	HV-volley TS	<u>FH-volley US</u>
	FH-volley US	BH-volley TS	BH-volley US	HV-liner TS (+)	BH-volley US	FH-liner US (+)
5	FH-volley US	BH-volley TS	BH-volley US	OH-smash	BH-volley US	HV-volley TS
	FH-kill	FH-lob (+)	<u>FH-volley US</u>	FH-volley TS	FH-kill	OH-smash (+)
6	FH-kill	HV-liner TS	<u>FH-volley US</u>	FH-volley TS	FH-kill	HV-volley US
	<u>FH-liner US (+)</u>	<u>FH-volley TS</u>	FH-kill	FH-volley TS	FH-volley TS	<u>BH-volley US</u>
7	<u>HV-volley TS</u>	<u>FH-volley TS</u>	FH-kill	FH-volley TS	FH-volley TS	<u>BH-volley US</u>
	FH-liner TS	FH-liner US (+)	FH-volley TS	BH-volley TS	BH-liner US (+)	BH-liner TS
8	FH-liner TS	<u>HV-volley TS</u>	FH-volley TS	BH-volley TS	OH-smash	BH-liner TS
	FH-liner TS (+)	OH-volley TS (+)	<u>BH-volley TS</u>	FH-liner TS	BH-volley TS	BH-liner US
9	FH-kill	HV-volley US	<u>BH-volley TS</u>	FH-liner TS	BH-volley TS	BH-liner US
	FH-volley TS	<u>FH-volley TS</u>	HV-liner TS (+)	<u>FH-volley US</u>	FH-kill (+)	FH-lob (+)
10	FH-volley TS	<u>FH-volley TS</u>	OH-smash	<u>FH-volley US</u>	FH-liner TS	<u>HV-liner US</u>
	BH-volley US	<u>FH-volley US (+)</u>	BH-volley TS	FH-lob (+)	FH-kill	<u>FH-volley US</u>
11	BH-volley US	FH-liner TS	BH-volley TS	HV-liner US	FH-kill	<u>FH-volley US</u>
	wild card	FH-kill	BH-volley US	FH-volley TS(+)	<u>FH-volley US</u>	wild card
12	wild card	FH-kill	BH-volley US	BH-volley US	<u>FH-volley US</u>	wild card

GAME SYMBOLS

VOLLEYS

The following codes are used on the player cards to distinguish the shots:

- **Bold-faced type** indicates a winning shot; the player wins the point.
- Underlined type indicates a losing shot; the player loses the point.
- Regular type indicates a volley shot; the ball is volleyed to the other player.
- *Italicized type* indicates the player approaches the net.
- An addition sign (+) indicates the shot executed by the player if the opposing player approaches the net.
- If no addition sign accompanies the shot, the shot is executed when the opposing player does not approach the net.
- The abbreviation TS indicates a shot hit with topspin.
- The abbreviation US indicates a shot hit with underspin.

GAME RULES

The server rolls the 20-sided die. The player will use the appropriate numbers indicated by category (first serve or second serve). Players will only use the second serve category when the player rolls a number that coincides with a “fault” on the first serve. After a point is won, the player serves again, rolling the 20-sided die and using the first serve category. The player continues serving until the game is over, when the opposing player takes over service for the next game.

If the player rolls an **ace**, the player has served a shot not returnable by the opposing player. Hence, the other player cannot volley; the player automatically wins the point and rolls the 20-sided die again for the next serve.

If the player rolls a return, the opposing player rolls the three six-sided die to determine the simulated returnable volley.

If the player rolls a fault on the first serve, the player rolls the 20-sided die again and then must use the numbers in the “Second Serve” category. The same rules apply for an **ace** or return served on the second serve as explained above. However, if the player serves a fault on the second serve, this means the player has double-faulted, and the opposing player wins the point.

VOLLEY EQUIPMENT & PROCEDURE

A player will use the volley portion of the card to return a serve, and to return every subsequent volley shot from the opposing player.

A player will need three six-sided dice, with one die distinguishable from the other two dice, usually a die of a different color or different size. The three dice are to be rolled simultaneously, with the distinguishable die determining the column (1-6) and the other two dice determining the row (2-12). Once these numbers are rolled, the player will look in the appropriate cell to determine the shot to be executed. For example, if the player rolls a three on the distinguishable die, a four and a five on the other two dice, the player will look in cell (3,9) and execute the appropriate shot within that cell. The player will execute the shot by interpreting the font-type and symbols specified earlier.

SCORECARDS

Figure 3 displays the point scorecard, and Figure 4 displays the game and set scorecard. Each player needs a marker to keep track of the score. These markers can be bottle caps, coins, etc. and must be distinguishable. Each player will need two markers, one for the point scorecard, and one for the game scorecard.

Figure 3: Point Scorecard

DEUCE	ADVANTAGE
30	40
LOVE	15

Figure 4: Game and Set Scorecard

Games

Player 1

1 2 3 4 5 6

Player 2

1 2 3 4 5 6

Sets

Player 1

1 2

Player 2

1 2

MATCH SCORING RULES

Female tennis players play best of 3 sets, and male tennis players generally play best of 5 sets, although male tennis players may play best of 3 sets.

SET SCORING RULES

A set consists of a series of games. The first player to win 6 games in a set wins the set, and the player must win by at least 2 games. Otherwise, these scenarios will play out:

If Player A leads a set 6 games to 5, and Player A wins the next game, then Player A wins the set 7 games to 5.

If Player A leads a set 6 games to 5, and Player B wins the next game, then the set is tied 6 games to 6. When a set is tied 6 games to 6, the players play a tiebreaker to determine who wins the next game, and consequently the set 7 games to 6.

The rules of the tiebreaker:

The player who was in line to serve the next game serves the first point of the tiebreaker, and each player alternates serves after each point.

Instead of the traditional 15-30-40 scoring format, a point scored by a player counts as 1 point. The first player to win 7 points wins the game and consequently the set, and a player must win by at least 2 points.

GAME SCORING RULES

A player is determined to serve the first game. Players alternate serve every game thereafter until the match is over. To determine the first server, each player rolls the 20-sided die. Whoever rolls the higher number is the first server. If the players roll the same number, the players roll until one player rolls a higher number than the other.

Games are scored on a 15-30-40-game point basis. Therefore, if Player A has 40 and wins the next point, Player A wins the game. However, there are exceptions:

If Player A leads 40-30, and Player B wins the next point, the score is now 40-40, which is referred to as "*Deuce*". If Player A wins the next point, this is referred to as "*Advantage Player A*". If Player A wins the next point, Player A wins the game. If Player B wins the next point, however, the score returns to "*Deuce*". This procedure continues until a player wins the game.

PROFESSIONAL SCORING RULES vs. MY SCORING RULES

The game scoring rules used in professional tennis are identical to my game. In professional tennis, an “ordinary advantage set” may be played in the third or fifth set of a three-set or five-set match respectively. In my game, a set tiebreak will always be used. Basically, this means a set in professional tennis may exceed 13 games; in my game, the maximum number of games in a set will be 13 (a player will win 7 games to 6).

WILD CARD OPTION

Listed below are the results for each wild card on the player cards.

- 1 -- You inadvertently hit the umpire in the side of the head with an errant shot, prompting the crowd to erupt in laughter and cheers. **Win 8 points**
- 2 -- You throw a fit that would make John McEnroe cringe. Lose 10 points
- 3 -- You huddle with your coach to develop a new strategy. **Win 7 points**
- 4 -- You "land" a bird perched on the net with a shot. Lose 7 points
- 5 -- You jam your thumb, which causes short term, but very intense pain. Lose 5 points
- 6 -- Your significant other wears an outfit that proves to be a major distraction for you. Lose 10 points
- 7 -- Your opponent is intimidated by your icy glare. **Win 5 points**
- 8 -- The sun is in your eyes (a LEGITIMATE excuse). Lose 3 points
- 9 -- Don Sillione, the Mafia leader, watches stoically, but gives you a subtle nod of confidence. **Win 7 points**
- 10 -- You take a swig of "Blue Thunder" energy drink, giving you an extra boost. **Win 5 points**
- 11 -- You trip over a broken shoelace. Lose 2 points
- 12 -- You use a towel to wipe off the sweat, thereby giving you better aerodynamics to reach the ball faster. **Win 3 points**
- 13 -- You let a heckler get to you. Lose 5 points
- 14 -- You spot a grasshopper on the side of the court, giving you extreme confidence. **Win 10 points**
- 15 -- You switch to a better racket. **Win 5 points**
- 16 -- You break many strings in your racket. Lose 3 points
- 17 -- You hit a squirrel running across the court. Lose 5 points
- 18 -- You reach into your gym bag and rub your Ball State shorts for good luck. **Win 10 points**
- 19 -- You develop a temporary case of paranoia, believing the ball boys and ball girls are "out to get you". Lose 5 points
- 20 -- You fake an injury, which gives your opponent false superior confidence. **Win 5 points**

Section III: Simulation

Player Feedback

My parents were generous enough to be my experimental players and play a match simulation. My father controlled Jennifer Capriati. My mother controlled Martina Hingis. Figure 5 presents this set simulation, played on hard court. The remainder of the match is played exactly like the first set. Martina Hingis won the match in straight sets, 6-4, 6-3. This match lasted approximately 90 minutes. Keep in mind, however, that I had to record every shot, so this accounts for some of this time.

My parents were relatively impressed with the game. They were particularly impressed with the different symbols and typeface I used to classify shots. They caught on very quickly to my symbols and typeface. Although at that time I hadn't color-coded my player cards according to court, they thought this was a clever idea as well. They also were quickly able to pick up on the procedures of my game (knowing when to roll the appropriate dice, being able to find the appropriate cell for each roll of the dice, etc.). They really enjoyed my "wild card" concept. Most "wild card" items enticed hearty laughter.

However, they did mention that the game was a bit too time-consuming. If this had been a three set match, this game easily would have been over two hours long. I readily noticed this criticism as well. My father also noticed a subtle inaccuracy: when a player returns a serve, he/she usually does not try to hit a particular shot. He/she is just trying to return the shot by getting the racket on the ball, and he/she hopes not to return a "soft ball", which means the opposing player has plenty of time to set up for the next shot, leaving the player at the opposing player's mercy. This is a valid point, but I am not sure how to fix it.

Overall, my parents were receptive to my game, especially my father. He wants to play me sometime, because he knows he will never beat me again in a real game of tennis, but he will have a chance to beat me at my game.

Section IV: Summary

Creating “Game, Set, Match” was a very gratifying experience for me. During this process, I was able to gain a somewhat better understanding of what designing a game entails. For my game specifically, I learned that creating a game is more of a cumulative process. In my game, most steps needed to be completed before I could build on creating the next step. I always thought most games could be divided into several segments and combining these completed segments simultaneously would create a finished product. I also learned that pinpoint accuracy and minute details play an integral role on creating a more realistic, life-like game. When playing a mathematical game based on compiling statistics, if the assumed statistics are corrupt, even slightly, the error in the results will be minimal. Furthermore, if the results are based on a series of games, these slight errors will be compounded significantly, and the error in the results will be magnified. Ironically, my game is based on original assumptions that may in fact be significantly incorrect. However, my game would be practically impossible to create if I were not able to compose my base statistics.

I am pleased with the way my game turned out. I consider it a player-friendly game in that it can be played solely for fun or it can be played by an avid fan who wishes to compile his or her own statistics. However, with more time I would make a few adjustments. First, I would devise a way to make the initial return of a serve more realistic, instead of my assumption that the returning player executes a particular shot. Second, I would reverse my volley percentages with the combined winning and losing percentages. For most players, the volley percentages are

Figure 3: SET SIMULATION

JENNIFER CAPRIATI vs. MARTINA HINGIS

JENNIFER CAPRIATI		MARTINA HINGIS
	Game 1, Set 1	
	Serve: Capriati	
<u>Fault</u>		
Return		HV-liner TS
	0 - 15	
Ace		
	15 - 15	
<u>Fault</u>		
Return		<u>HV-volley US</u>
	30 - 15	
<u>Fault</u>		
Return		BH-volley TS
	30 - 30	
Return		OH-smash
	30 - 40	
Return		HV-volley US
HV-volley US		BH-volley US
	Games 0 - 1	
	Game 2, Set 1	
	Serve: Hingis	
FH-liner TS		Return
	15 - 0	
<i>FH-volley TS</i>		Return
	15 - 15	FH-lob (+)
FH-kill		Return
	30 - 15	
FH-kill		<u>Fault</u>
	40 - 15	Return
OH-smash		<u>Fault</u>
	Games 1 - 1	Return
	Game 3, Set 1	
	Serve: Capriati	
Ace		
	15 - 0	
<u>Fault</u>		
Return		BH-volley US
	15 - 15	
<u>Fault</u>		
Return		<u>HV-volley US</u>

30 - 15
Figure 3 (con't)

<u>Fault</u> Return			FH-kill
	30 - 30		
Return FH-liner TS BH-volley TS			HV-dink BH-volley TS (+)
	40 - 30		
Ace			
	Games 2 - 1 Game 4, Set 1 Serve: Hingis		
BH-volley US			Return HV-volley US
	0 - 15		
	0 - 30		Ace
FH-kill			Return
	15 - 30		
HV-volley TS HV-volley US			Return FH-volley TS
	15 - 40		
BH-volley US			Fault Return OH-smash
	Games 2 - 2		
	Game 5, Set 1 Serve: Capriati		
Return			BH-volley US
	15 - 0		
<u>Fault</u> Return			BH-volley US
	15 - 15		
Ace			
	30 - 15		
Return HV-volley TS			BH-volley TS
	30 - 30		
<u>Fault</u> Return FH-kill			BH-volley TS
	40 - 30		
Ace			
	Games 3 - 2		
	Game 6, Set 1 Serve: Hingis		
			Ace

BH-volley TS	0 - 15	Return
	Figure 3 (con't)	
	15 - 15	
FH-volley US	30 - 15	Return
FH-kill	40 - 15	Return
<u>FH-volley US</u>	40 - 30	Return
FH-volley TS		Return
FH-volley TS		HV-dink
	Deuce	HV-liner TS
<i>BH-volley US</i>		Return
<u>FH-volley US</u>		HV-volley US
	Advantage Hingis	
HV-volley US		Return
HV-dink	Deuce	HV-dink
FH-volley US	Advantage Capriati	
<u>HV-dink</u>	Deuce	Return
		<u>Fault</u>
<i>BH-volley TS</i>		Return
	Advantage Hingis	FH-kill
FH-lob (+)	Deuce	Return
<u>BH-volley US</u>	Advantage Hingis	Return
		<u>Fault</u>
		Ace
	Games 3 - 3	
	Game 7, Set 1	
	Serve: Capriati	
Return	0 - 15	HV-volley TS
Ace	15 - 15	
Ace	30 - 15	
<u>Fault</u>	40 - 15	<u>FH-volley TS</u>
Return		FH-volley TS
Return		

	40 - 30	
Return		BH-volley US
	Deuce	
	Figure 3 (con't)	
Ace		
	Advantage Capriati	
Ace		
	Games 4 - 3	
	Game 8, Set 1	
	Serve: Hingis	
	0 - 15	Ace
	0 - 30	Ace
		<u>Fault</u>
<u>BH-volley US</u>	0 - 40	Return
HV-volley US		Return
FH-kill	15 - 40	FH-volley US
		Return
WILD CARD		
<u>lose 10 points</u>		
	Games 4 - 4	
	Capriati loses all (4) points in Game 9	
	Games 4 - 5	
	Capriati loses all (4) points in Game 10	
	Games 4 - 6	
	Hingis wins set 1 — 6 Games to 4	

between 25% and 40%. However, I believe this percentage is still too low. I would revise the volley percentage to equal the winning game percentage on each court, instead of my original assumption of one minus the winning game percentage on each court. This would alter the new volley percentages to between 60% and 75% for most players. I feel this would be somewhat more accurate.

Also, if I had more time I would create an advanced version of this game, much like the Strat-O-Matic baseball game. The advanced game would be a more detailed version of the game, adding more intricacies to the game, such as a fatigue factor, and a factor based on the opponent's strength and weaknesses. I could even include a climate factor. In short, I would try to make the game as realistic as possible.

As I have previously stated, I realize my game is not enticing to everybody. So if I were to market my game, my game would be marketed toward sports fans and fans of board/card/dice games over the age of 12. Ideally, the Strat-O-Matic Game Company would market my game, and the primary marketing strategy would be word-of-mouth advertising by avid Strat-O-Matic fans. Therefore, I would prefer quality fans, not just a quantity of fans.

My primary goal for creating "Game, Set, Match" was to create a realistic, entertaining tennis game that was fun to play and had easily recorded statistics. I also wanted to prove that mathematics, although often intimidating, could also be considered fun. Hopefully, I will be able to improve my game in the future. If not, I encourage any future Ball State University Honors College student to revise my game to make it even more realistic and entertaining.

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